Applications of Weigh-In-Motion Data in Transportation Planning

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Applications of Weigh-In-Motion Data in Transportation Planning

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Abstract: Participation in the SHRP and Canadian-SHRP (C-SHRP) long term pavement performance monitoring programs has prompted all state and provincial highway agencies in the United States and Canada to install at least one weigh-in-motion (WIM) scale. The WIM scales provide not only the traditional traffic monitoring data, but also a very large amount of detailed data for individual vehicles including length, speed, axle weights and axle spacing. Because the WIM data are often associated only with pavement research, many potential users are not yet aware of (a) the capabilities of WIM technology, (b) the type of data available, and (c) the opportunities to utilize WIM data in their areas of expertise.

This paper briefly describes traffic monitoring data generated by typical WIM installations. A number of practical examples show that WIM data are useful for a wide range of transportation planning and decision-making purposes. The specific application areas discussed include:

* planning and programming of transportation facilities
* pavement design and rehabilitation
* apportionment of pavement damage
* compliance with vehicle weight regulations
* development of geometric design standards
* compliance and regulatory policy development of truck dimensions
* safety analysis
* traffic operation and control
* analysis related to highway bridges

WIM data can be used in all these application areas. Its usefulness cuts right across the organizational structure of any highway agency. Thus, WIM data should be considered corporate data, and should be managed accordingly.

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1/ Introduction

During the past few years, there has been a rapid and widespread introduction of weigh-in-motion (WIM) technology and automatic vehicle classification (AVC) technology in the United States and Canada. The main impetus for this has been the participation in the SHRP and C-SHRP long term pavement performance monitoring programs, which mandate a detailed automatic monitoring of traffic loads. Already, all major state and provinical highway agencies have installed, or are in the process of installing at least one WIM scale. The Ontario Ministry of Transportation (MTO) experimented with the earliest WIM equipment in the mid 1970s, and has been operating at least one WIM scale more or less continuously since the early 1980s [1]. The MTO is currently operating four in-highway WIM scales, six WIM sorter scales at Truck Inspection Stations (TIS) and, to comply with the SHRP and C-SHRP guidelines, is planning to install three additional WIM scales in 1991.

The existing and planned WIM scales are providing, and will continue to provide, a large amount of detailed traffic monitoring data for individual highway vehicles, such as axle spacing and axle weights, and vehicle length and speed. This is in addition to the traditional aggregated traffic characteristics, such as hourly and daily vehicle volumes. The installation and operation of WIM scales, and the associated traffic data retrieval and analysis, is not an easy or inexpensive task. It is desirable to ensure that the wealth of traffic monitoring data generated by WIM scales is properly utilized.

It is often assumed that WIM data are only applicable to pavement research, because of their association with the SHRP and C-SHRP pavement research effort. As a result, many potential users of WIM-type traffic monitoring data do not know:

(a) the data monitoring capabilities of WIM technology
(b) the type of data available
(c) how the data can be utilized within their area of interest.

The objective of this paper is to show, by practical examples, that WIM data are useful for a wide range of transportation planning and decision-making purposes. The treatment of any individual area is, by necessity, quite brief, in order to provide a comprehensive overview of all the main areas of application.

In this report, axle and gross vehicle weights (GVW) results are presented in kilograms, and axle spacings in metres and vehicle speeds in kilometres per hour: the units in which Ontario regulates vehicle loads and dimensions.

2/ Description of Traffic Monitoring Data Provided By WIM Scales

A typical WIM scale consists of magnetic loops and axle sensors embedded in the pavement, and a microcomputer housed in a roadside cabinet. Magnetic loops and axle sensors respond to axles passing over the pavement by generating electric signals. The signals are processed by the computer and are transformed into engineering parameters including instantaneous vehicle speed, vehicle length, distances between consecutive axles, and axle weights. An annotated example of an individual vehicle record provided by a WIM scale is shown in Figure 1.

The majority of data used in this study were obtained from two WIM scales, one installed on Hwy 7N and the other on Hwy 402. The Hwy 7N scale is located in an eastbound truck lane of a six-lane suburban (Metropolitan Toronto) arterial road, and uses bending plate technology [2]. The Hwy 402 scale is located in an eastbound truck lane of a four-lane rural freeway (near Sarnia), with a speed limit of 100 km/h, and uses piezoelectric cable technology [3]. Compared to static conditions, the scales provide dimensions accurate within 2 to 3%, gross vehicle weights within

about 5%, and axle loads within about 5 to 12%. Accuracy depends on vehicle dynamics (e.g., vehicle configuration and speed) and pavement roughness in the vicinity of the scale.
The WIM computer can store a record for each vehicle passing over the scale, as well as some selected summary data. These data are then transferred to a personal microcomputer in the office. Here they can be verified, edited and analyzed to meet the different application requirements.

Common to all WIM data applications is the need to classify individual vehicles into distinct categories. An example of the basic MTO vehicle classification scheme is given in Figure 2. The scheme resembles that used by the FHWA Traffic Monitoring Guide [4] . However, unlike the FHWA Guide, it attempts to classify non-passenger vehicles not only according to number of axels and number of connected units, but also according to axle configuration. Thus, for example, there is a specific category for 3S2 trucks (Category 7 in Figure 2).

While the Ontario scheme recognizes 14 highway vehicle classes, some applications discussed later require a more specific or detailed classification scheme. Table 1 shows one method for identification of 6-axle tractor-semitrailers that are loaded close to their allowable gross weight. The semitrailer is of a tri-axle design, having a fixed dual axle unit at the rear and a liftable, "belly axle," usually at least 2.54 m ahead of it. The scheme relies on knowledge of the impact of vehicle weight and dimension regulations on truck design. This was done by constructing a "filter" which specifies limits on various truck weight and dimension parameters so that only those trucks of interest are selected.

Considering the variety of vehicles and the large samples of vehicles analysed, there must be a certain level of speculation associated with any vehicle classification scheme based on WIM data. There is no reason to believe that these uncertainties have a significant effect on the observations made from the results or on the more global conclusions presented herein.

3/ Utilization of WIM Data

To enhance the understanding of and to clarify the various ways in which WIM data can be utilized for transportation planning and decision making, the following discussion is divided into nine general application areas, some of which may overlap.

3.1/ Planning and Programming of Transportation Facilities

Any WIM scale installed on a highway is, basically, a continuously operating traffic counting station. It can generate not only traditional traffic volume characteristics, such as the AADT and the thirtieth highest hourly volume used for planning and programming of transportation facilities, but also a wealth of additional detailed data for individual highway vehicles.

When planning the installation of new permanent traffic counters, or the replacement of existing ones, consideration should be given to upgrading the counters into WIM scales. The cost of upgrading is mainly due to higher quality axle sensors and a more powerful computer in the roadside cabinet. Installation and operating costs, such as highway closure during installation, provision of power and communication lines at the site, system maintenance and data retrieval, comprise the bulk of the total cost. They are not much influenced by the type of traffic counting device. The benefits of upgrading can be significant.

3.2/ Pavement Design and Rehabilitation

WIM data have been closely associated with pavement design because traffic loads constitute the basic pavement design parameter [5]. For pavement design and evaluation purposes, the effect of traffic loads on pavement structural damage has been traditionally expressed using the concept of

Load Equivalency Factors (LEF). The equivalency factors equate the damaging effect of any given axle, or axle combination, to that of a standard axle. For convenience, LEFs have been related to the standard axle load of 8 160 kg (18,000 lb) carried on a single axle with dual tires, called the Equivalent Single Axle Load (ESAL).

Understanding of the number of ESALs associated with different truck types, in different highway corridors and during different times, is now shaped mainly by WIM data. As an example of the usefulness of WIM data, Table 2 compares the average ESAL per truck obtained from WIM scales with that estimated by the OPAC truck prediction subsystem [6]. The latter is currently used for design, and was established before the advent of WIM scales. The existing prediction methodology is seen to underestimate the average ESALs per truck by a factor of 2 or more. The ESALs reported herein are related to flexible pavements with a structural number equivalent to 5 [5].

While Table 2 shows the average ESALs per truck, a rather global measure of pavement traffic load, WIM technology enables changes in ESAL, for specific vehicle types during specific time periods, to be evaluated. For example, Figure 3 illustrates a year-long variation in average weekly ESALs for 3S2 tractor-semitrailers on Hwy 7N. (For definition of 3S2 trucks refer to Figure 2).

The WIM data can provide the main building block for developing procedures for predicting ESALs for pavement structural design. What is required, basically, is to obtain volume estimates for major truck categories and their corresponding average ESALs. Detailed step-by-step procedures are readily available.

3.3/ Apportionment of Pavement Damage

In many jurisdictions, there is a general tendency to set truck licence fees in proportion to the highway resources (pavement damage) consumed. The WIM scales can quantify pavement damage contributions of different truck classes, as shown in Figure 4 for Hwy 402. For example, trucks with 6 or more axles constitute less than 20% of the total truck volume, but are seen to be responsible for more than 50% of pavement damage.

3.4/ Compliance With Vehicle Weight Regulations

3.4.1/ In-highway WIM Scales

WIM scales can provide realistic and detailed insight into vehicle axle and gross overloads. The assessment is realistic because WIM scales can operate continuously and are unobtrusive. It is detailed because by generating weight and dimension records for individual highway vehicles, they enable assessment of overloads during a specific time period and for a specific truck category.

It should be recognized that WIM scales do not directly provide a valid estimate of violation rates because of the impact of vehicle dynamics and other factors on weight estimates. While WIM scales cannot be used at this time for vehicle weight enforcement, they are sufficiently accurate to identify substantial deviations from regulatory limits.

An example result in Figure 5 shows the compliance with weight regulations for liftable axles on 6-axle tractor-semitrailers with a dual axle unit at the rear and a liftable "belly" axle at least 2.54 m ahead of it. This truck type is the most common among the trucks with liftable axles, and is also the most prone for axle overloads.

The trucks were identified using the filter defined in Table 1 which was applied to individual vehicle records obtained by the Hwy 402 and Hwy 7N WIM scales during a 1-month period in

1990. The same data set is used for the other examples given in this report, unless otherwise stated. The filter produced a sample of 72 trucks from the Hwy 7N WIM scale, and 184 trucks from the Hwy 402 scale. The small numbers arise because the range of GVW of the selected trucks is very narrow (condition in filter of Table 1), ranging from about 49 000 to about 55 500 kg.

A few selected observations, related only to liftable axles, and based mainly on Figure 6, are given below. (A more comprehensive discussion of GVW and axle overloads for 6-axle tractor-semitrailers with liftable axles is given in [7]. This reference also describes weight compliance observed for 5 and 6-axle semitrailers without liftable axles).

* Loads on the liftable axles ranged from 2 000 to 17 000 kg for each highway. The allowable load limit on the liftable axle, considering that its distance from the surrounding axles is more than 2.5 m, is 10 000 kg.

* There was somewhat better load compliance on Hwy 402 than on Hwy 7N. About 21% of liftable axles were overloaded on Hwy 402 compared to about 37% on Hwy 7N. This may be due, partly, to the proximity of the Hwy 7N WIM scale to intersections, where turning trucks would be raising the liftable axle in preparation for turning or after making a turn, and partly because the Hwy 402 WIM scale is close to a TIS. Regarding the liftable axle overloads, it should be noted that they apply only to a selected group of trucks with the GVW close to the allowable limit (Table 1, criterion h).

* Because the GVW of all trucks investigated was within 1 000 kg of their allowable (total) GVW, when the loads on the liftable axles were significantly lower than their allowable load, say less than 8 000 kg, the slack due to these underloaded liftable axles had to be compensated for by overloading the surrounding axles. About 20% of liftable axles were underloaded on Hwy 7N.

Analyses of this type, based on statistically relevant samples obtained by WIM scales, are far removed from simplistic conclusions such as "10% of trucks are overloaded."

3.4.2/ WIM Scales Near Truck Inspection Stations

WIM scales located near TIS can be used to evaluate the effectiveness of weight enforcement programs and help in developing cost-effective enforcement strategies. This can be accomplished, for example, by comparing compliance rates, determined by a continuously operating WIM scale, achieved by different compliance enforcement strategies employed at the TIS (e.g., an intensive versus a spotty enforcement strategy).

3.4.3/ WIM as Sorter Scale

To facilitate the enforcement of weight regulations, TIS on high truck volume highways have been equipped with WIM scales. These scales are referred to as sorter scales because they are used to sort incoming trucks into two categories: (a) those that clearly comply with weight regulations, and (b) those that should be weighed at a static scale. Figure 6 shows a schematic layout of a TIS incorporating a sorter scale. Upon entering the TIS area, trucks with no payload can be directed to bypass both the sorter scale and the static scale. When this option is used, the weight data obtained from the sorter scale are no longer representative of the entire truck population and cannot be used for certain applications. Whenever feasible, the sorter scale should be used to weigh all trucks entering the TIS. Even in this case the data can be biased: the proclivity of trucks to avoid TIS is well-known.

3.5/ Development of Geometric Design Standards

The rational development of highway geometric design standards (turning radii and width of traffic lanes at intersections, dimensions of loading and unloading facilities, design of truck climbing lanes etc.) requires the knowledge of vehicle weights and dimensions. In particular, the dimensions of the most common, and from the space requirement aspect, one of the most demanding large truck configurations -- the 5-axle tractor-semitrailer. The realistic assessment of dimensions of existing vehicles requires a large truck population sample, which can easily be provided by WIM scales. The utilization of WIM data is illustrated for one of the key parameters governing the space requirements for turning movements of a 3S2 truck -- its semitrailer wheelbase. A detailed analysis and interpretation of the observed dimensions of 5-axle tractor-semitrailers on geometric standard development, in terms of the overall truck length, tractor and semitrailer wheelbase and the drive and trailer axle spreads, is given in [7].

The relationship between semitrailer wheelbase (the distance from its kingpin to the centre of its rear dual axle, Figure 1) and the maximum low-speed offtracking offset (the distance between the turning radii of the steering axle and the rear axle) is shown in Figure 7, while Figure 8 shows the observed trailer wheelbase distribution. Some of the observations regarding trailer wheelbase distribution, as they apply to the development of geometric standards, are summarized below.

* On Hwy 7N, the distribution appears to be bi-modal. The first peak, around 8.8 m (29 ft), is believed to be associated primarily with 40-foot container chassis. The second peak, around 10.7 m (35 ft), is more likely to be associated with older 13.7 m (45 ft) semitrailers now relegated to local uses. On Hwy 402, the predominant wheelbase is around 11.9 m (39 ft), which is typical of a 14.7 m (48 ft) semitrailer now used for long-distance hauling.

* The maximum observed semitrailer wheelbase was about 13 m on Hwy 402 (Figure 8). This wheelbase results in an offtracking of about 7 m (Figure 7). However, considering the generally shorter wheelbase distances observed for local Hwy 7N traffic and the longer wheelbase distances observed for long-distance Hwy 402 traffic, the geometric standards need not be applied uniformly to all transportation facilities.

3.6/ Truck Dimensions: Compliance and Regulatory Policy Development

The knowledge of existing truck dimensions can be used to assess the consequences of regulatory changes in truck dimensions and/or the need to except the existing truck configurations for the time being (grandfathering). This issue is connected with the development of geometric design standards. However, while the development of geometric design standards tends to simply reflect the existing situation, exploration of the policy development issues is more pro-active. For example, the following observations may be formulated when considering the results of the semitrailer wheelbase distribution given in Figure 8, from a compliance perspective:

* The Canadian "Memorandum of Understanding on Interprovincial Heavy Vehicle Weights and Dimensions" [9] establishes an upper limit of 12.5 m for a semitrailer wheelbase. Twenty-eight trucks on Hwy 7N (0.39%) exceeded this limit, compared to 194 (0.49%) on Hwy 402. The majority of these exceeded the 12.5 m limit by no more than 0.6 m.

* Some of the problem trucks may be carrying a long, indivisible load and operating under permit. It would be useful to know "who" such trucks are, particularly in terms of their body style and commodity. However, the WIM data alone cannot provide such detailed information.

3.7/ Safety Analysis

Safety emerges as a major issue in all debates or polemics about changes in vehicle weights and dimensions and, invariably, it is concluded that adequate information about safety implications of the proposed changes is lacking [10]. WIM data can contribute to analysis of safety issues by providing detailed information on vehicle types using highway facilities, and vehicle behaviour on highway facilities.

3.7.1/ Vehicle Types Using Highway Facilities

The knowledge of mileage travelled by various vehicle types (exposure rate) is a prerequisite for evaluation of their accident rates. The accident rate, (the number of accidents divided by the exposure) is instrumental in identifying the influence of vehicle design parameters on vehicle safety.

Trucks are often registered in several jurisdictions or in a jurisdiction other than the one in question. It is, therefore, difficult to estimate mileage travelled by different truck classes and, thus, to obtain accident rates for different truck types. WIM data can help in establishing truck exposure measures particularly for facilities where WIM scales have been installed. For example, referring to Figure 4, truck type 3S2 (defined in Table 1) comprises about 55% of the total truck volume on Hwy 402. The volume percentage of 3S2s can be directly related to the percentage of accidents involving the 3S2s on this facility.

Another descriptive parameter useful in accident studies (and provided by WIM data) is the gross vehicle weight. It has been observed that the accident rates of unloaded trucks are significantly higher than the rates for loaded trucks [11].

3.7.2/ Vehicle Behaviour on Highway Facilities

The unobtrusive presence of WIM scales can provide a reliable description of vehicle driving patterns, and enable rational assessment of truck driving behaviour. In this summary report, driving behaviour is described using only simple frequency distribution functions for vehicle speed and headway. It is certainly possible to study more complex functions such as the relationship between vehicle speed, headway, GVW, and time of day for different vehicle categories, and to provide data to develop and manage police enforcement strategies.

(a) Vehicle Speed Distribution

WIM scales routinely provide instantaneous vehicle speeds (Figure 1). Excessive vehicle speed, and particularly speed differentials between different vehicles, is considered to be one of the main causes of accidents. It is also one of the main parameters governing energy consumption. Overloaded and speeding trucks may constitute an additional safety hazard.

Figure 9 shows vehicle speed distribution for cars and trucks, during the day and at night, derived from the Hwy 402 WIM scale data. Data were obtained for four consecutive weekdays, without any precipitation, in March of 1991. It should be stressed that the WIM scale is in one of the truck lanes of this four-lane rural freeway, and that low traffic volumes (about 300 vehicles per hour in the WIM lane during daytime and 75 vehicles per hour at night) enable a large degree of traffic operational freedom.

Overall, data in Figure 9 indicate that truck drivers are more disciplined than car drivers. Some specific observations:

* The majority of the cars were speeding. The speed limit on this facility is 100 km/h (about 60 miles/h). During daytime, about 53% of all cars exceeded 110 km per hour, while at night 42% of all cars exceeded this speed. The corresponding numbers for trucks were 16% and 10%, respectively.

* Compared to cars, truck speed distribution is more uniform. Looking at the extremes, during daytime, 1.3% of cars had speeds less than 80 km/h compared to only 0.3% of trucks. At the high end, 1.3% of cars (in the truck lane) exceeded the speed of 130 km/h compared to 0.1% of trucks.

(b) Headway Distribution

According to Ontario's Highway Traffic Act [11], maintaining "reasonable and prudent" headway is mandatory for all drivers. There is an extra stipulation for drivers of commercial vehicles who, while driving at speeds exceeding 60 km/h, "shall not follow within 60 metres of another motor vehicle."

WIM scales routinely provide a time stamp, truncated to the nearest second, for all individual vehicle records. Only this routine time measurement precision was available for data used in this exploratory study. A more focused study of headway distribution would require software modification giving time measurements in tenths of a second.

Figures 10 and 11 compare the difference in headway distributions of cars and trucks. The figures use the same data set as that used for Figure 9. The greater discipline of truck drivers, indicated by the speed distribution, is also indicated by the headway distribution. Some observations:

* During daytime, 7% of all cars followed other cars with a one second headway, while only 2.5% of trucks did so. Nevertheless, considering an average truck speed of 100 km/h or 27.8 m/s, more than 2.5% of all trucks appear to be in violation of the Ontario Highway Traffic Act headway requirement.

* Also during daytime, 3.5% of all trucks were following other trucks with a headway of 1 second, while only 2.5% of trucks were following cars with this headway. The difference in the headway distribution for these two cases was found to be statistically significant.

* Trucks tend to travel in convoys. This is particularly evident at night when 7.5% of all trucks had headways of less than 6 seconds compared to only 1.1% for cars.

3.8/ Traffic Operation and Control

There are several computerized analytical models which are used for analysis, optimization, and control of traffic operations on highway facilities. In order to derive full benefits from the more sophisticated analytical models, it is necessary to divide the traffic flow into vehicle categories according to vehicle weight and length, and frequency of occurrence. For example, the model TRARR [13], used for analysis of undivided highways, can accommodate up to 16 vehicle types, and FOMIS [14], a simulation model for freeway sections, can accommodate up to 100 vehicle types. Undoubtedly, WIM supplied data can take advantage of the models' options and can increase their usefulness and accuracy.

3.9/ Analysis Related to Highway Bridges

Two levels of WIM data usage can be envisaged; to determine load levels used for reviewing the design and maintenance standards for bridges, and to determine load levels for a specific bridge structure.

(a) Review of Loading Requirements for Design and Maintenance

Periodic vehicle weight surveys are essential to determine loading standards for the design and maintenance of bridges [15]. The most recent load survey for Ontario was conducted in 1989. It was done manually, by measuring (with a tape) and weighing (with static scales) a selected sample of about 2000 trucks in 17 locations across the province. This type of survey could become obsolete as the number and accuracy of WIM scales increase. Some preliminary work on utilizing WIM data, obtained by an instrumented highway bridge, was done by Agarwal and Bakht [15]. At any rate, WIM scale results can supplement manual surveys and have the advantage of realistically capturing overloaded trucks, which are usually one of the main reasons for conducting such surveys.

(b) Load Levels for Specific Bridge Structures

The loading and safety concerns regarding a specific bridge structure can be addressed by temporary installation of a portable WIM scale. The WIM scale can provide the loading information to the bridge owner, and can also provide a warning to drivers of trucks which are overloaded for the specific bridge structure.

4/ Discussion

The above discussion on using WIM scale data and extracting specific information of interest in different application areas is not exhaustive. It simply illustrates possible usage in the traditional application areas. Other application areas may include modeling of goods movement and macroeconomic applications (input - output models). For example, Pennsylvania DOT uses WIM scale data to determine total cargo weight transported by the highway on a long term basis [16]. WIM scales, combined with automatic vehicle identification (AVI) systems, may be used for fleet management and management of truck traffic through long-distance corridors (Crescent project). On a somewhat unrelated topic, WIM scales can be installed on remote airports to document aircraft movements (e.g., type of aircraft, how loaded, time of operation).

5/ Conclusions

1. This paper has demonstrated through examples, that WIM data can provide insights not previously available, to a wide range of issues that cut across the organization of a highway agency.

2. WIM technology can provide statistically reliable samples that should supplant older labour-intensive manual survey methods.

3. WIM scales, because of their unobtrusiveness and continuous operation, can provide truly unbiased data yielding a realistic long term picture of highway usage and driver behaviour.

4. Currently available WIM data do not satisfy all requirements connected with analyzing impacts of regulatory policies on truck weights and dimensions.

5. When planning the installation of new permanent traffic counters, or the replacement of the existing ones, consideration should be given to upgrading the counters into WIM scales.

6. The demonstrated usefulness of WIM data requires that it be treated as corporate data. Highway agencies should consider establishing dedicated (formal) WIM data banks to facilitate data storage and retrieval as a service to potential users. WIM scale operation and WIM data storage should be integrated with other traffic data gathering and storage processes as the corporate resource.

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Table 1/ Criteria Identifying 6-axle Tractor-Semitrailers With a Liftable Axle

Criteria for Truck Definition

(a) 6-axle trucks

(b) single (steering) - dual (tractor) - single (liftable) - dual (trailer) axle arrangement

(c) axle 2-3 spacing from l.07 to l.83 m

(d) axle 3-4 spacing greater than 4.00 m

(e) axle 4-5 spacing greater than 2.40 m

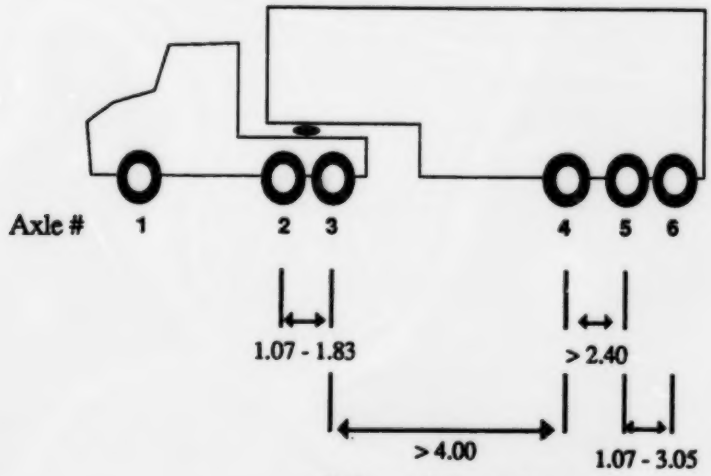
(f) axle 4-5 spacing greater than axle 5-6 spacing

(g) axle 5-6 spacing from l.07 to 3.05 m

(h) gross weight within 1000 kg of allowable load

Explanation

The first item simply ensures the proper number of axles. The second is descriptive, and may be redundant. Item (c) covers the known range of drive axle spreads. Item (d) ensures that the filter captures semitrailers at least l0 m (32 ft) long, so it will exclude tractors pulling 7 m (23 ft) tridem container chassis. Items (e) and (f) ensure the liftable axle is properly separated from the trailer tandem axle, according to either Quebec, Ontario, or Michigan regulations. Item (g) covers the known range of trailer axle spreads. The final item ensures the gross weight is close to the allowable limit.



all dimensions are in m

Table 2/ Comparison of Average Equivalent Standard Axle Loads per Truck

Location Facility type	Average ESAL per truck	
	Based on WIM Measurements	OPAC Estimate[1]
Hwy. 7N Urban arterial road	1.40	0.40
Hwy. 402 Rural freeway	1.60	0.67

1 *Source: Reference 5*

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(910)LANE £3  TYPE 7  GVW 33.1 tonnes   LENGTH 1849 cm
18-K ESAL 4.058 SPEED 57 km/h Mon Jan 15 08:54:46 1990
```

UNIT	SEPARATION (cm)	WEIGHT (kg)
1		4432
2	515	9517
3	148	9618
4	763	5343
5	180	4226

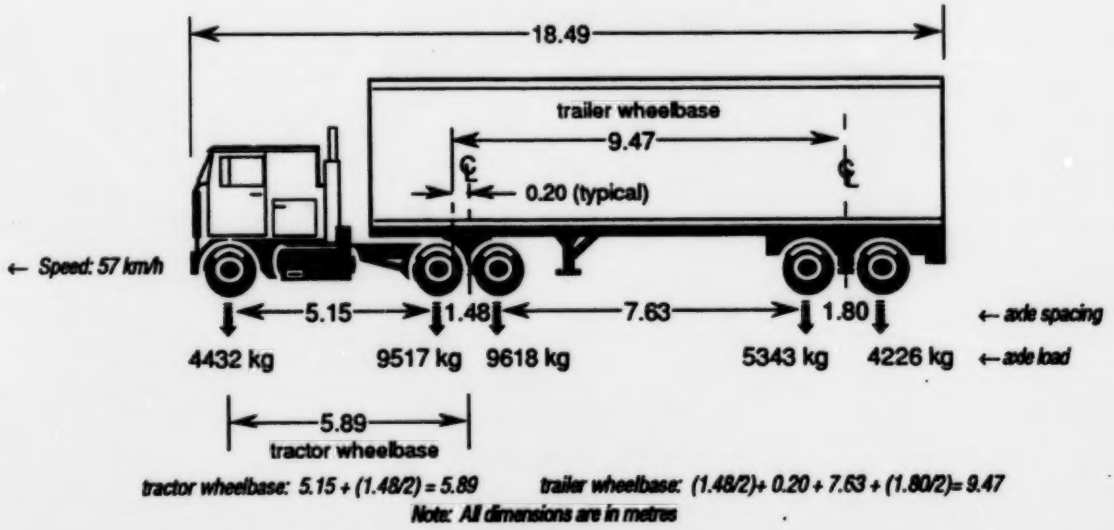


Figure 1/ Individual truck record from IRD WIM scale and its interpretation

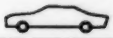
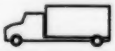
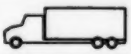
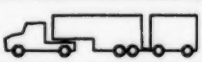
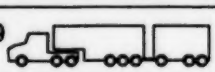
Class	Type	Description
1	PVLC 	**Passenger cars** 2-axle vehicles with spacing from 1.2 to 3.9 m
2	2 	**2-axle trucks** axle spacing from 3.9 to 15.0 m
3	3 	**3-axle trucks** with a dual axle spacing up to 2.4 m
4	UD-3	**All other 3-axle trucks**
5	2S2	**4-axle trucks** 2-axle tractor with one dual axle semitrailer dual axle spacing up to 2.4 m largest tractor and semitrailer axle spacing from 2.4 to 15.0 m
6	UD-4	**All other 4-axle trucks**
7	3S2	**5-axle trucks** 3-axle tractor with one dual axle semitrailer dual axle spacing up to 2.4 m largest tractor and semitrailer axle spacing from 2.4 to 15.0 m
8	UD-5	**All other 5-axle trucks**
9	3S3	**6-axle trucks** 3-axle tractor with a 3-axle semitrailer tractor dual axle spacing up to 2.4 m trailer axle spacing up to 2.6 m largest tractor and semitrailer axle spacing from 2.4 to 15.0 m
10	UD-6 	**All other 6-axle trucks**
11	3S2-2	**7-axle trucks** 3-axle tractor with two semitrailers or with one semitrailer and one trailer; the first semitrailer has a dual axle tractor dual axle spacing up to 2.4 m largest tractor axle spacing up to 5.0 m first semitrailer dual axle spacing up to 3.0 m largest 1st and 2nd trailer axle spacing from 5.2 to 15.0 m
12	UD-7	**All other 7-axle trucks**
13	UD-8	**All 8-axle trucks**
14	UD-9 	**All trucks with 9 or more axles**

Figure 2/ Ontario vehicle classification scheme

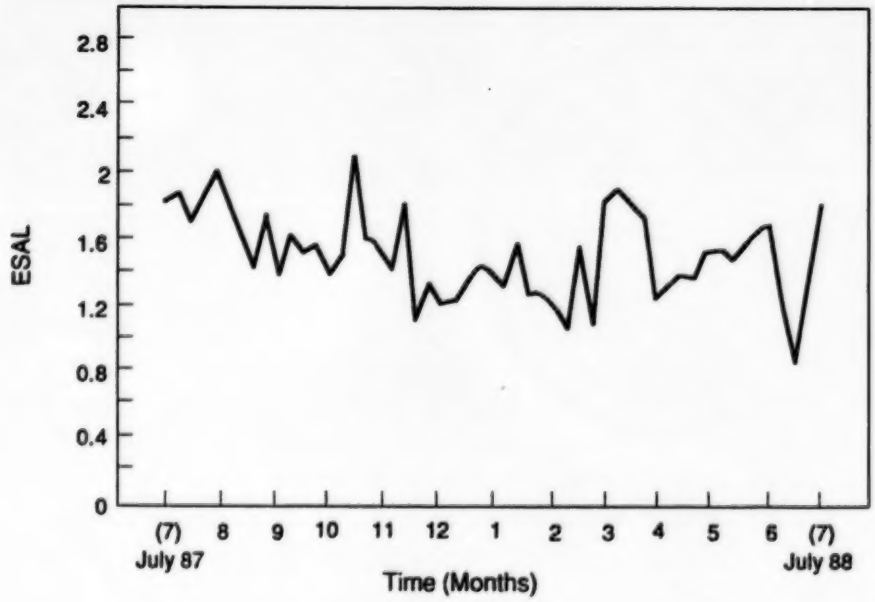


Figure 3/ Variation in weekly ESALs for 3S2 tractor semitrailers Hwy 7N, lane 3

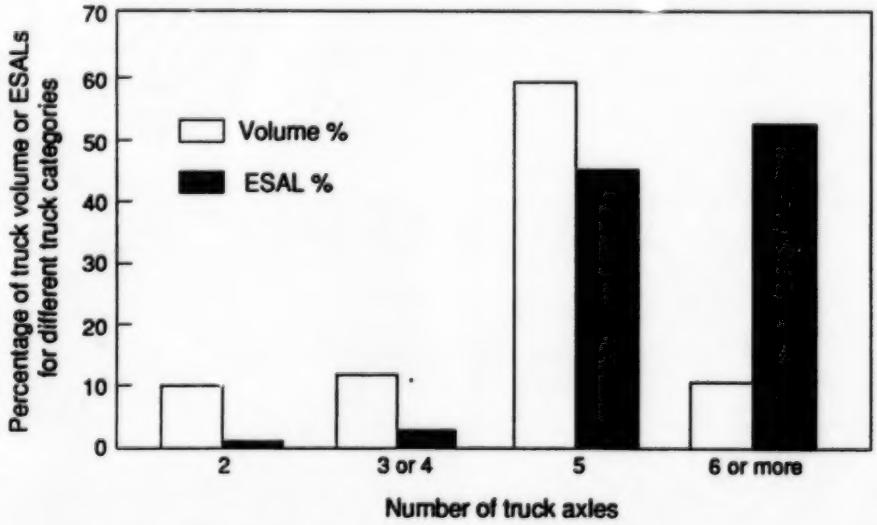


Figure 4/ Pavement damage contribution by different truck categories Hwy 402, 1989

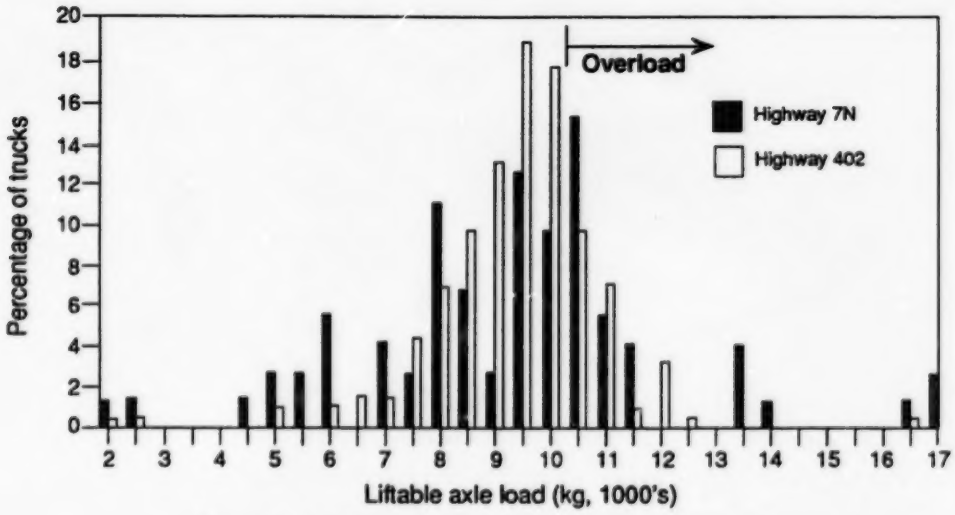


Figure 5/ Liftable axle load distribution for a selected group of 6-axle tractor-semitrailers

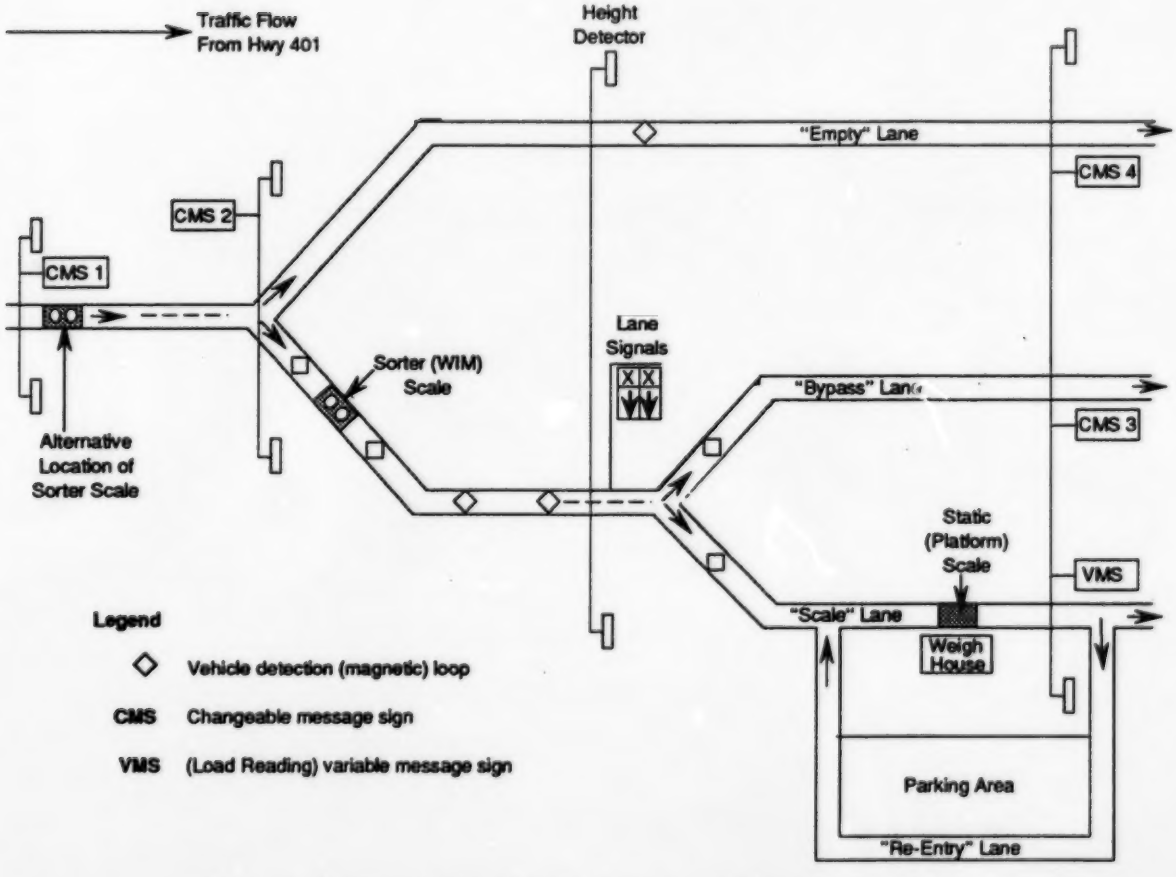


Figure 6/ Schematic layout of truck inspection station with sorter scale Hwy 401, Putnam South

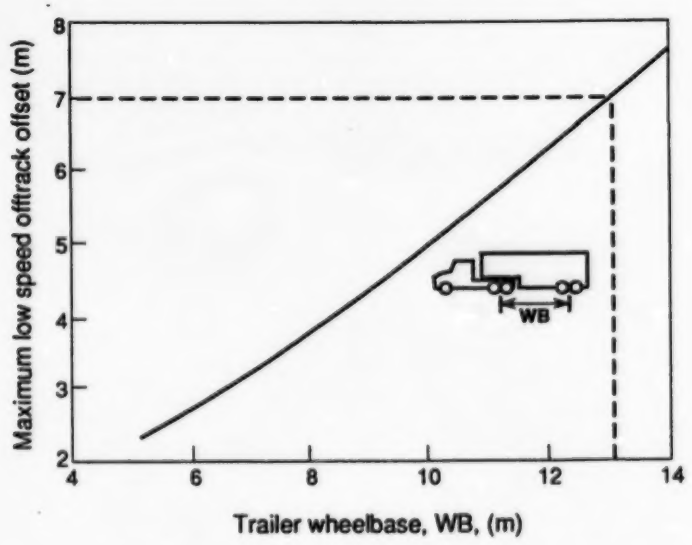


Figure 7/ Maximum offset during low-speed turns
Source: Reference 8

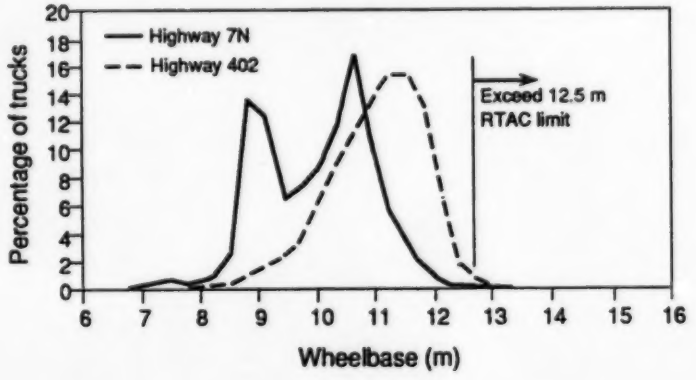


Figure 8/ Trailer wheelbase distribution for
5-axle tractor-semitrailers

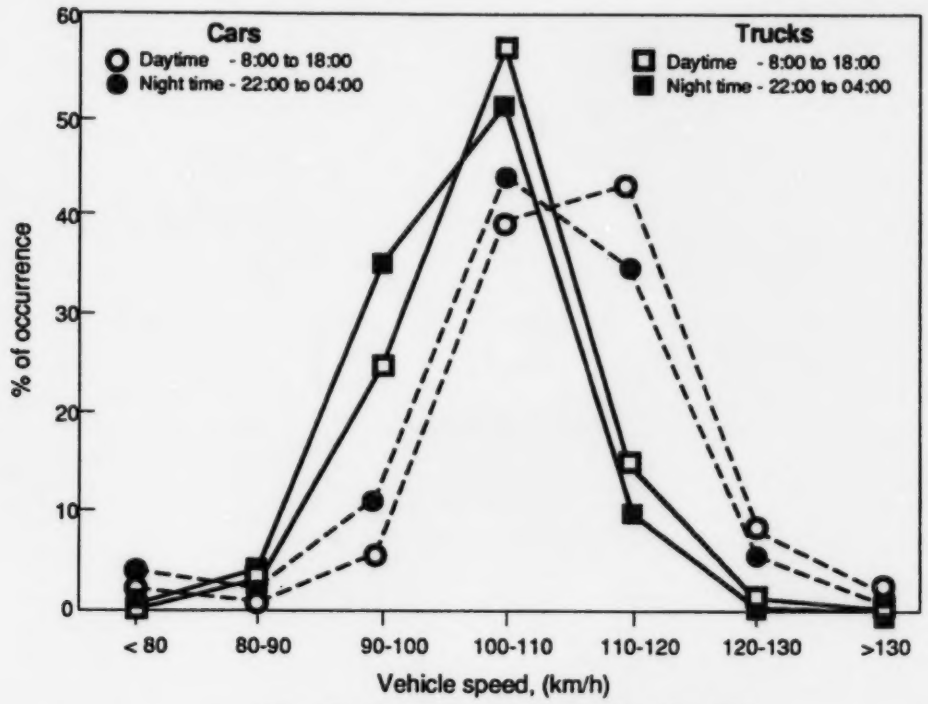


Figure 9/ Vehicle speed distribution, Hwy 402, truck lane, March 19 to 22, 1991

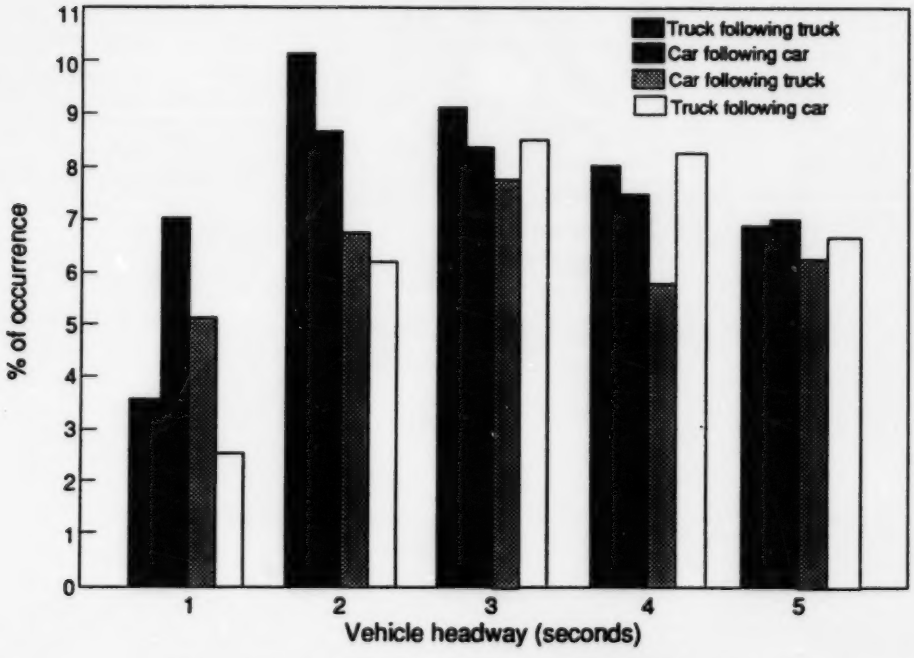


Figure 10/ Daytime vehicle headway distribution, Hwy 402, truck lane, March 19 to 22, 1991

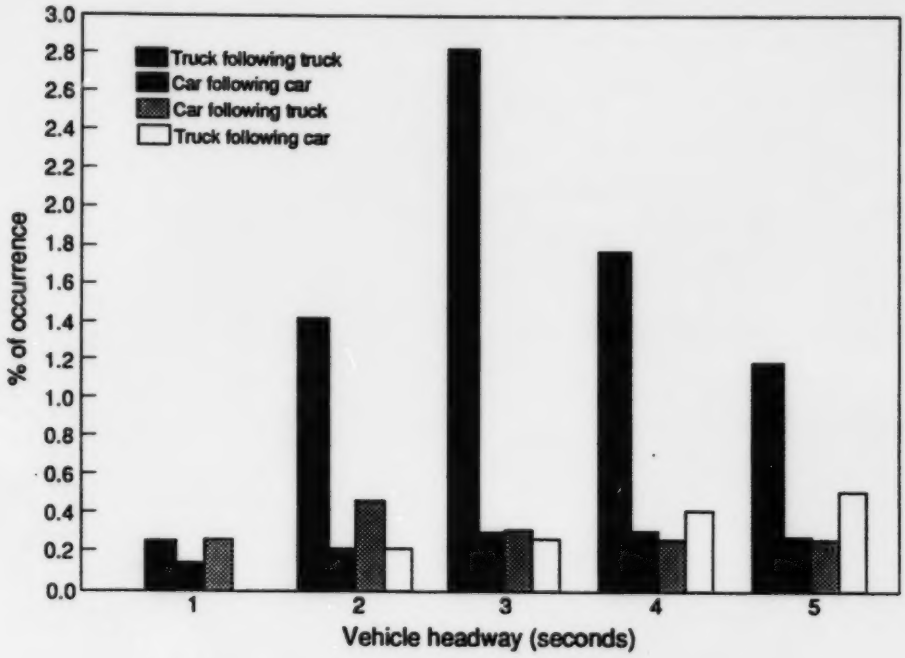


Figure 11/ Night time vehicle headway distribution, Hwy 402, truck lane, March 19 to 22, 1991